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Design of Rectangular Nanostrip Patch Antenna for Dual Band Terahertz Applications

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ABSTRACT

Rectangular nanostrip patch antenna with Graphite material at nano scale has been designed and optimized using Ansoft HFSS. The objective of this project is to design nanostrip patch antenna for Dual Band Terahertz application by simulation through the structural and functional optimization according to the desired design specification such as antenna dimensions like Length (L), Width (W) and Substrate parameters such as Relative permittivity (εr), Substrate thickness, Radiation parameters and Band width. Substrates with low dielectric constant are generally preferred for maximum radiation. Hence we prefer graphite which is having dielectric constant as unity and which is also a super conductor at nano scale. The conducting patch can take any shape. Because of less complexity to analyze and require minimum numerical computations, Rectangular & circular configurations are the most commonly used. Hence graphite substrate and graphite rectangular patch is designed at nano scale and it is simulated with Ansoft HFSS 13.0 and with antenna design kit 1.0. In view of this design, selection of width and length of the patch are the major parameters along with the feed line and probe. The confined design of Patch antenna is simulated at nano scale. Resultant Characteristics such as return loss, gain, directivity, polarization, scattering parameters and radiation pattern were analyzed and proved that this antenna is suitable for Dual Band Terahertz application.

Keywords: Ansoft HFSS, Antenna design kit 1.0; nanostrip; substrate; Graphite; Terahertz; Dual band; Relative permittivity (εr).

INTRODUCTION

An antenna is a device that is made to efficiently radiate and receive radiated electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for application such as Antenna radiation patterns, Power Gain, Directivity Polarization. Our society is in need of miniaturized efficient antenna for developing quantum communication system. Structurally and functionally miniaturized antenna play a vital role in developing efficient quantum communication system. In this research work, Graphite material is chosen at nano scale because of thermal and structural stability of carbon nano tube at quantum scale. Graphite nano structures deployed in substrate and patch of antenna results the antenna characteristics at Dual Band Terahertz level in frequency spectrum and also it improvises the spectral filtering, antenna coverage, antenna polarization, gain, bandwidth, cut off frequency and minimizes the impedance. A Nanostrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure (1). The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Nanostrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. Nanostrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a nanostrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the nanostrip line and the radiating patch. In this research, we deploy graphite sheet at nano scale (with relative permittivity=1, relative permeability =1, bulk conductivity =70000 Siemens/m) is use as rectangular substrate and rectangular patch above the surface of the substrate as perfect E shaped with feed line and probe at nano dimensions. Entire structure is simulate using Ansoft HFSS 13.0 with antenna design kit 1.0

DESIGN SPECIFICATION

A. Design Consideration

The three essential parameters for the design of a rectangular Nanostrip Patch Antenna:

Resonant Frequency (fr): The resonant frequency selected for this design is 750 THz.

Dielectric constant of the substrate (εr): The dielectric material selected for our design is graphite which has a dielectric constant of 1. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.

Height of dielectric substrate (h): For the nanostrip patch antenna to be used Dual Band Terahertz region, it is essential that the antenna is not bulky. Hence, the height of the substrate is selected as 20.5nm.Hence, the essential parameters for the design are:

f_r = 750THz, ε_r = 1, h = 20.5nm

B. Design Calculation

The actual length, L of the patch is,

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} = 200 \text{ nm}$$

The effective dielectric constant due to the air dielectric boundary is given by:

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\,\frac{h}{W}\right]^{-\frac{1}{2}} = 1$$

To determine the extension of length, we use this formula:

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}\right] = 14.0462 \text{ nm}$$

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{reff}}} = 400 \text{ nm}$$

The actual length, L of the patch is using the following formula:

$$L = \frac{\lambda_g}{2} - 2\Delta L = 171.9076 \text{ nm} \approx 172\, nm$$

The ground plane dimensions would be given as:
Lg = 6h + L = 295 nm and Wg = 6h + W = 323 nm

$$\mathrm{I}_1 = \int_0^{\pi}\left[\frac{\sin\left(\frac{\beta_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 sin^3\theta d\theta = -2 + \cos(x) + x\mathrm{Si}(x) + \frac{\sin(x)}{x} \quad (1)$$

Where

$$x = \beta_0 W = \frac{2\pi}{\lambda_o}W = \frac{2\pi}{c/f}W = 3.142857 \approx 3.1429$$

The calculated x is Cosine and Sine Integrals
$\therefore x = 3.1429 \rightarrow \sin(x) = -0.001307346$
Therefore, solve for equation (1);

$$\mathrm{I}_1 = -2 + \cos(x) + x\mathrm{Sin}(x) + \frac{\sin(x)}{x} = -3.0042597\, rad$$

I_1 as calculated previously was used to calculate the value of conductance as shown below;

$$G_1 = \frac{\mathrm{I}_1}{120\pi^2} = -2.535 \times 10^{-3} siemen$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{\beta_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 \times J_0(\beta_0 L\sin\theta) sin^3\theta d\theta$$

Where J_0 using the asymptotic methods that it can be shown as following,
$J_0 \cong 1$ So,≈ 0
To find the value of y_0, we use equation below;

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})}cos^2\left(\frac{\pi}{L}y_0\right) \Rightarrow \quad \text{y0=80 nm}$$

$$y_1 = \left(\frac{L}{2} - y_0\right) + \frac{\lambda_g}{4} = 106\, nm$$

SIMULATION SOLUTION AND RESULTS

The software used to model and simulate the Nanostrip patch antenna using Ansoft HFSS. It is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MMICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the *S* parameters, VSWR, current distributions as well as the radiation patterns. The inset feed is designed to have an inset depth of 80nm, feed-line width of 40nm and feed path length of 140nm. A frequency range of (0.1

to 5000) THz is selected and 204 frequency points are selected over this range to obtain accurate results. The center frequency is selected as 750 THz at which the return loss is minimum. The bandwidth can be calculated from the XY rectangular plot. The optimum feed depth is found to be at Yo = 80nm where a Return Loss of -5.9 dB is obtained. The bandwidth of the antenna for this feed point location is calculated as,

1st Resonant frequency (f_{r1}) :
f_{r1} = 320.2906 THz

Cut-off frequency (f_{c1}) = (f_2-f_1)/2
= (332.6789-300.0866)/2 = 16.2962 THz

2nd Resonant frequency (f_{r2}) : f_{r2} =2069.0241 THz
Cut-off frequency (f_{c2}) = (f_4-f_3)/2
= (2081.1436-2054.1170)/2 =13.5133THz

Band width (BW_1)= f_2-f_1
= (332.6789-300.0866) = 32.5923 THz
Band width (BW_2)= f_4-f_3
= (2081.1436-2054.1170) = 27.0266 THz

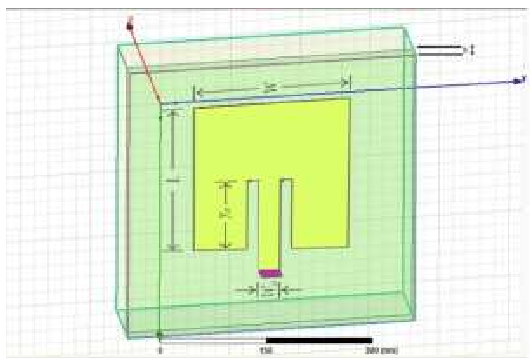

Fig.1: 3D design of nanostrip patch antenna

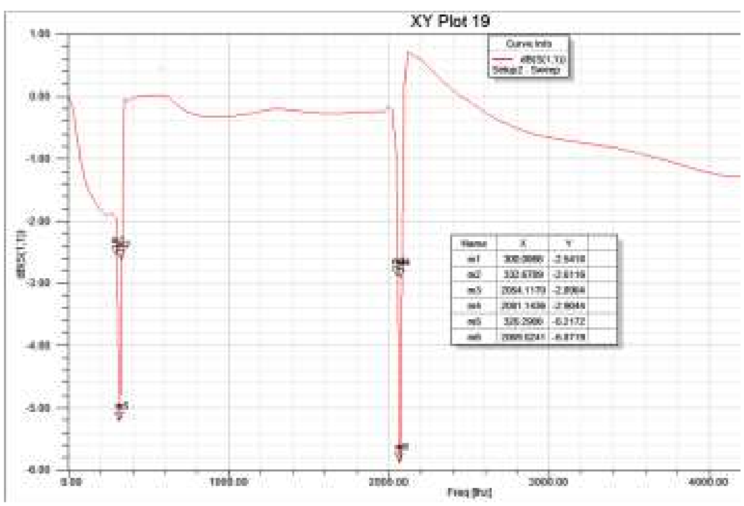

Fig.2: 2D XY Rectangular Plot_Graphite

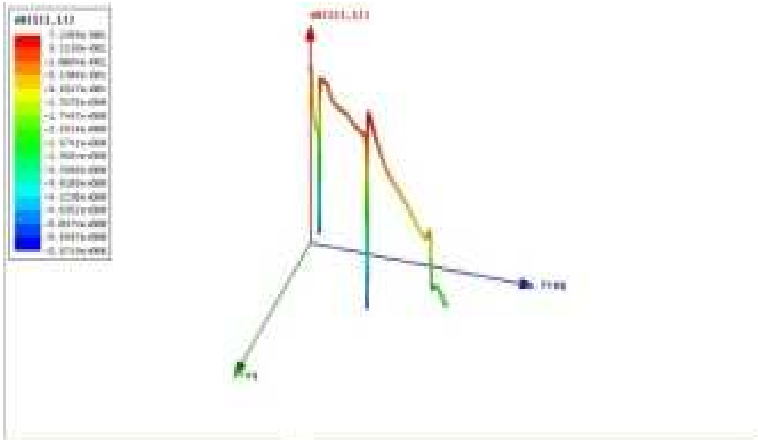

Fig.3: 3D Rectangular Plot

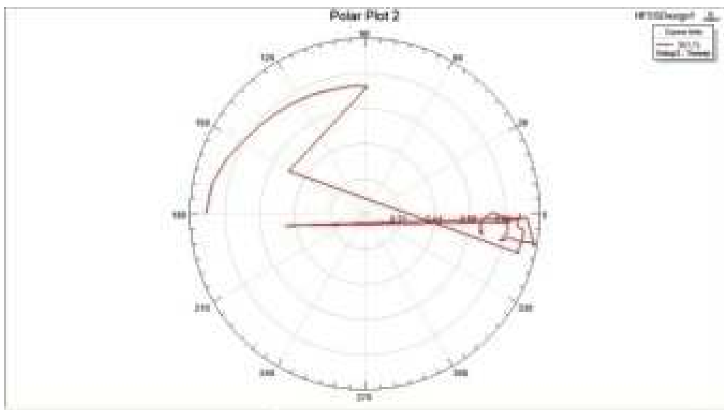

Fig.4: 2D Polar Plot_graphite

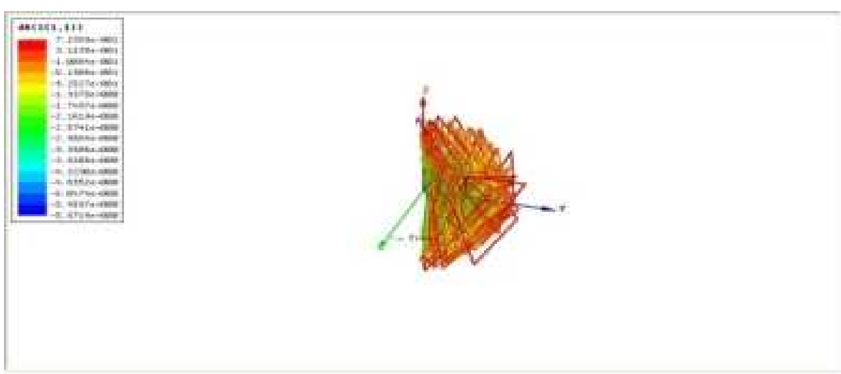

Fig.5: 3D Polar Plot

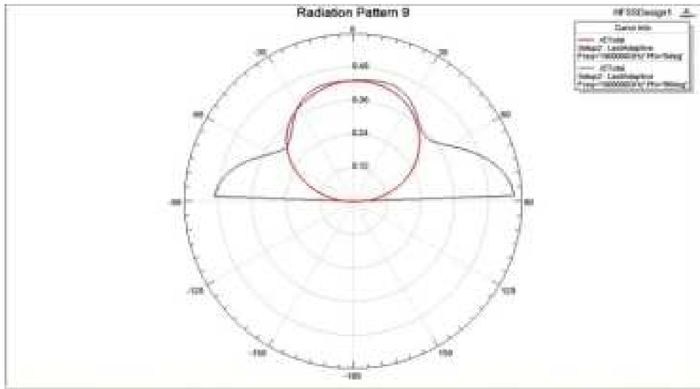

Fig 6: Radiation Pattern

CONCLUSION

The simulations results obtained by HFSS simulator is proved that the proposed Design Of Rectangular Nanostrip Patch Antenna in graphite nano structure for Dual Band Terahertz Application can be good candidate for band of 300THz to 3000 THz region of frequency spectrum, due to its miniature size, and its good performances. It can be used for Investigations of Semi conductor material, Dielectric material and Foot print of Biological materials, Surveillance of International security threats like as atomic weapons, drugs and explosives, Sensing, Near field imaging and Narrow band communication for petroleum and other industrial applications

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